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May 16, 1995

Dr. Paul Kepple
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Dear Sir,

Enclosed please find the final report for our contract, ONR contract number N00014-91-K-2005, entitled, *Dense Plasmas Produced with Ultra-Short Pulse and High Intensity Lasers for X-Ray Laser Research*, D. Umstadter and G. Mourou, principal investigators. Please feel free to call us if you have any questions about the content of this report.

Regards,

Donald Umstadter
Res. Scientist and Adj. Prof.

encl: final report

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A table-top sub-picosecond terawatt laser was used to study experimentally the atomic and plasma physics of plasmas that are relevant to the recombination and photo-pumping x-ray laser schemes. Experimentally, x-ray spectroscopy with simultaneous temporal and spectral resolution was used to characterize the line and continuum emission of soft x-rays emitted from a solid density plasma. Numerically, we developed our non-LTE time-dependent collisional-radiative numerical code, which was used to interpret the experimental results. It was found that the results depended critically on the laser contrast conditions, and that the x-ray pulsewidth could be arbitrarily adjusted by simply adjusting a single parameter, the laser intensity, and thus the peak temperature of the plasma. This novel ultrafast broadband radiation source in the soft x-ray region of the spectrum can be used for time-resolved dynamical studies in ultrafast science and pumping x-ray lasers. It was measured to be six orders of magnitude brighter, and three orders of magnitude shorter in pulse duration (less than one picosecond), than any existing synchrotron source.

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# Final Report on ONR Contract #N00014-91-K-2005: *Dense Plasmas Produced with Ultra-Short and High-Intensity Laser Pulses for X-Ray Laser Research*

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Submitted to Dr. Paul Kepple, ONR Scientific Officer

## Abstract

A table-top sub-picosecond terawatt laser was used to study experimentally the atomic and plasma physics of plasmas that are relevant to the recombination and photo-pumping x-ray laser schemes. Experimentally, x-ray spectroscopy with simultaneous temporal and spectral resolution was used to characterize the line and continuum emission of soft x rays. Numerically, we developed a non-LTE time-dependent collisional-radiative numerical code, which was used to interpret the experimental results. It was found that the results depended critically the laser contrast conditions, and that the x-ray pulsewidth could be arbitrarily adjusted by simply adjusting a single parameter, the laser intensity ($I$), and thus the peak temperature of the plasma. This novel ultrafast broadband radiation source in the soft x-ray region of the spectrum can be used for time-resolved dynamical studies in ultrafast science and pumping x-ray lasers. It was measured to be six orders of magnitude brighter, and three orders of magnitude shorter in pulse duration ($\leq$ one picosecond), than any existing synchrotron source. It is predicted that, by changing the level-population dynamics, this short-pulse high-temperature blackbody radiation source can significantly increase the gain of transient recombination x-ray lasers.

## Technical Objective

Although several x-ray laser schemes that employ short-pulse pump lasers have been proposed, very little is known experimentally and numerically about the actual plasma conditions that are attainable when short-pulses interact with matter. We used the table-top terawatt ($T^3$) laser at the Center for Ultrafast Optical Science (CUOS) to study experimentally the atomic and plasma physics of plasmas that are relevant to the recombination and photo-pumping x-ray laser schemes. Concurrently, we developed our non-LTE time-dependent collisional-radiative numerical code, which was used to interpret the experimental results.

## Major Accomplishments

- We have recently developed a novel ultrafast broadband radiation source in the soft x-ray region of the spectrum that can be used for time-resolved dynamical studies in ultrafast science and pumping x-ray lasers. It was measured to be six orders of magnitude brighter, and three orders of magnitude shorter in pulse duration ($\leq$ one picosecond), than any existing synchrotron source. By virtue of being table-top and relatively inexpensive, it is also more readily available to a wider research community. And, since the x-rays are absolutely synchronized to the laser that produced them, they have the additional advantage of being capable of being used for jitter-free pump-probe measurements of photoinduced processes. As such, this source could have enormous potential impact on research of ultrafast dynamics in the fields of physics, chemistry and biology.

  Time-resolved single-shot Aluminum and Gold spectra were measured for the first time using a high-contrast sub-picosecond laser pulse.

  It was found that only with high-laser contrast could short pulses be obtained.

  It was found that the x-ray pulsewidth could be arbitrarily adjusted by simply adjusting this single parameter ($I$), and thus the peak temperature of the plasma.

- Our fluid code has been benchmarked against the experiment. By solving the wave equation simultaneously with the fluid equations, we are able to include the effects of the ponderomotive force on the evolution of the density profile, and the correct energy deposition by inverse bremstrahlung absorption. In our experiments, the evolution of the density profile was inferred from measurements of the Doppler shift of the light reflected from the expanding critical surface. The model was found to agree with experiments to within 10%. Besides being of interest in improving our basic physics understanding, these results will have an impact on photo-pumping x-ray laser candidates, since it has been shown that Doppler-broadening of expanding plasmas can

detune the resonance of overlapping lines, or bring into resonance adjacent lines.

- Polarization measurements of kilo-electron-volt x-ray line emission were used to study the anisotropy of the electron distribution and the non-local transport in an ultra-short gradient scalelength laser-produced plasma. The results compared favorably with the predictions of our kinetic code, and are important for a good understanding of the ionization balance.

## Summary of the overall impact of the research

Up to now, the only ultrafast *continuous* radiation sources available were in that part of the electromagnetic spectrum between the ultraviolet and the infrared. However, with this new XUV 'white light' source, the range of ultrafast absorption spectroscopy and imaging can now be extended to a higher-photon-energy regime. The source is essentially tunable since a portion of the spectrum may be selected by use of either a multilayer mirror or a dispersive optic, such as a grating or Bragg crystal.
Examples of applications include: material structural dynamics such as melting, temporal backlighting of dense plasmas, imaging of live biological cells, time-resolved absorption spectroscopy of either quantum controlled photo-initiated chemical reactions or transient energy states of laser-ablated materials (for material processing and thin-film deposition), photosynthesis dynamics, photo-electron spectroscopy (for condensed-matter surface studies), inner shell atomic ionization, and nonlinear optics with x rays.
In relation to the proposed work on applications to x-ray lasers, it is predicted that, by changing the level-population dynamics, this short-pulse high-temperature blackbody radiation source can significantly increase the gain of transient recombination x-ray lasers [J. Aprusezes and D. Umstadter, submitted to JOSA B (1995)].

## Four key words

x ray, spectroscopy, lasers, ultrafast

## Related Publications

## Publications


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